Monday, July 27, 1998
IDPs AND MICROMETEORITES
1:30 p.m. Ussher Theatre

Chairs: S. Messenger
G. J. Flynn

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The Infrared Space Observatory Revolution: Implications for the Presolar Origins of Silicates in Anhydrous Interplanetary Dust Particles

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Messenger S.*
Oxygen-Isotopic Imaging of Interplanetary Dust

Nakamura K.* Klöck W. Romstedt J. Greshake A. Grund T.
Field-Emission Scanning Electron Microscopy and Transmission Microscopy Study of Interplanetary Dust Particles for the Rosetta Mission

Kehm K.* Flynn G. J. Sutton S. R. Hohenberg C. M.
Helium, Neon, and Argon Measured in Large Stratospheric Dust Particles

Pepin R. O.* Schlutter D. J.
Excess Helium-3 in Interplanetary Dust Particles

Dauphas N.* Robert F. Marty B.
Hydrogen, Nitrogen, and Neon Elemental and Isotopic Constraints on Cometary and Meteoritic Fluxes

Kolesnikov E. M.* Stepanov A. I. Gorid'ko E. A. Kolesnikova N. V.
Element and Isotopic Anomalies in Peat from the Tunguska Explosion (1908) Area are Probably Traces of Cometary Matter

THE ISO REVOLUTION: IMPLICATIONS FOR THE PRESOLAR ORIGINS OF SILICATES IN ANYDROUS INTERPLANETARY DUST PARTICLES. J. P. Bradley [1], L. P. Keller[1], D. E. Brownlee[2], and T. Snow[3], [1]MVA Inc, Norcross GA 30093, USA, [2]Department of Astronomy, University of Washington, Seattle WA 98195, USA, [3] Center for Astrophysics and Space Astronomy, University of Colorado, Boulder CO 80309-0389, USA (jbradley@mvainc.com).

Infrared (IR) spectroscopy provides a direct link between laboratory measurements of interplanetary dust particles (IDPs) and astronomical measurements of dust in space. Silicate minerals in IDPs produce a strong feature at ~10 µm (Si-O stretching). The 10 µm feature plus a ~20 µm feature (Si-O-Si bending) are among the most ubiquitous features observed (in absorption and emission) in astronomical IR spectra [1]. Although the shapes of IDP 10 µm features do not consistently match those observed in astronomical spectra [2,3] , glass-rich components of some IDPs (e.g. GEMS) exhibit 10 µm "silicate" features similar to those of some comets [3].

The Infrared Space Observatory (ISO) was launched in 1995 by ESA with spectrometers covering the 2.5–240 µm wavelength range [4]. The ability of ISO to cover the far IR region where additional features due to crystalline silicates are found has led to the discovery of crystalline forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$) together with glassy silicates in the circumstellar environments of both young and old stars [5]. ISO spectra of comet Hale-Bopp show a 10 µm silicate feature similar to P/Halley and other comets with major peaks at 9.3, 10, and 11.2 µm [6]. Prior to the ISO observations of Hale-Bopp, these peaks in comet spectra were tentatively assigned to pyroxene (9.3 and 10 µm) and olivine (10 and 11.2 µm). ISO's discovery of 18 µm, 23 µm, and 33 µm features provides dramatic confirmation that Hale-Bopp contains Mg-rich olivine (forsterite) [7]. (Mg-rich silicates were detected using mass spectrometry in comet Halley's dust [6]). The shape of Hale-Bopp's 10 µm "silicate" feature exhibits significant temporal variation, which may be explained by two silicates (forsterite and enstatite) with significantly different temperatures [8]. Warmer forsterite grains radiate over a range of heliocentric distances but cooler enstatite grains radiate only close to perihelion where a dramatic increase of the strength of the 9.3 µm and 10 µm peaks is observed. Enstatite may be as much as 12 times more abundant than forsterite in Hale-Bopp's dust [8].

The ISO data provide important new evidence of the cometary origins of the pyroxene-rich class of anhydrous chondritic IDPs, in accordance with earlier findings [9]. These IDPs are the only known class of meteoritic materials that contain submicrometer glassy silicates (e.g. GEMS), Mg-rich olivine (forsterite), and pyroxene (enstatite) grains. Some of these enstatite and forsterite grains exhibit crystallographic and trace element evidence of vapor phase growth [10,11]. Therefore, it is possible that IDPs contain pristine condensates formed in stellar outflows. The ISO Hale-Bopp data illustrate that the properties of silicate grains (e.g. temperature) can strongly influence the strength and shape of the 10 µm "silicate" feature in astronomical spectra. Such grain effects need to be considered when comparing laboratory IDP spectra with those of comets and other objects.

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TRACE ELEMENT CONTENTS OF L2011 CLUSTER FRAGMENTS: IMPLICATIONS FOR COMET SCHWASSMAN-WACHMANN-3 AS A SOURCE OF L2011 CLUSTER IDPS. G. J. Flynn[1] and S. R. Sutton[2], [1]Department of Physics, SUNY-Plattsburgh, Plattsburgh, NY 12901, [2]Department of Geophysical Sciences, The University of Chicago, Chicago, IL 60637.

Comets are believed to contain the most pristine samples of the original material from which our Solar System formed. However, interplanetary dust particles (IDPs) from comets are generally heated more severely on atmospheric entry than are IDPs from asteroids, thus most cometary IDPs experience significant thermal alteration. Messenger and Walker [1] recently identified a comet, Schwassman-Wachmann-3, which can deliver IDPs to Earth with a relatively low atmospheric entry velocity (~16 km/sec), resulting in less extreme entry heating than typical cometary IDPs. They suggest unusual cluster particles, having high D/H [1] and high He^3/He^4 [2], on L2011 may be from Schwassman-Wachmann-3 [1].

These L2011 cluster fragments all have lower He concentrations than typical IDPs. The traditional interpretation is that low He identifies particles which lost solar wind He during atmospheric entry heating [2]. However, Messenger and Walker [1] suggest the low He in L2011 cluster particles may have resulted from extremely short space exposure ages, and this is a key feature in their association of these particles with Schwassman-Wachmann-3. Supporting this, they cite measurements of trace element abundances on cluster fragments from the L2009 collector, flown at the same time as L2011, which show relatively high volatile contents [3] suggesting most L2009 cluster fragments experienced little thermal alteration during atmospheric entry.

We measured the trace element contents of fragments from 6 L2011 clusters on which He abundances and unusual He^3/He^4 ratios have been reported [2]. Of these, two—L2011 B17 (Cluster 8), and L2011F7 (Cluster 22)—showed extremely low Zn/Fe (~0.01 × CI). Nier and Schlutter [2] found very low He concentrations (0.7 and 0.6 $\times 10^{-3}$ ccSTP/gm) in their fragments from Clusters 8 and 22. The other four cluster fragments—L2011A10 (Cluster 4), L2011B16 (Cluster 5), L2011C13 (Cluster 11), and L2011E9 (Cluster 17)—had Zn/Fe ranging from 0.47 to 1.82, suggesting little loss of volatile elements on atmospheric entry. The He contents of fragments from these four clusters ranged from 1.4 to 2.7×10^{-3} ccSTP/gm, somewhat higher, in all cases, than the two particles with low Zn/Fe ratios.

The trace element and the He measurements were performed on *different* fragments from each L2011 cluster, and we know fragments of L2008 Cluster 5 exhibit significant heterogeneity in both Zn and He [4]. Nonetheless, the Zn/Fe and He-concentration data, taken together, suggest both indicators monitor the thermal pulse experienced during atmospheric entry and that the two low-Zn clusters experienced a loss of He due to that thermal pulse.

The four clusters exhibiting chondritic Zn/Fe ratios, indicating little atmospheric entry alteration, allow comparison of the He concentrations in less severely heated L2011 cluster fragments with those in other IDPs. The four L2011 fragments from clusters which have Zn/Fe >0.3 × CI have an average He content of 2.2×10^{-3} ccSTP/gm. In comparison, four clusters from the L2005 and L2006 collectors on which Zn/Fe is >0.3 × CI have He concentrations of 1.3, 22, 53, and 80×10^{-3} ccSTP/gm [5], averaging 38×10^{-3} ccSTP/ gm, more than an order-of-magnitude higher than the L2011 fragments. These measurements are consistent with L2011 cluster fragments having intrinsically low He contents.

The low He in L2011 clusters may result from an extremely short space exposure, consistent with the suggestion they are derived from Schwassman-Wachmann-3, or it may indicate the fragments measured for He are from interior regions of the original IDP, sampling material shielded from exposure to the solar wind.

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COMETARY ORIGIN FOR ANTARCTIC MICROMETEORITES: NEW EXPERIMENTAL EVIDENCES. M. Gounelle[1], M. Maurette[1], C. Engrand [2], and G. Kurat [3], [1]CSNSM 91405 Orsay Campus, France. [2]University of California at Los Angeles, Department of Earth and Space Sciences, Los Angeles CA 90095-1567, USA, [3]Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria.

Antarctic micrometeorites (AMMs) have been collected for the first time in 1987. The identification of their parent bodies has been difficult. Early measurements of the ^{26}Al /^{10}Be ratio [1] demonstrated that micrometeorites were small bodies (<1 cm) in space precluding them from being mere meteorite debris. However it is not well established whether this genuine interplanetary dust is of asteroidal or cometary origin (see [2] for a discussion). Conventional wisdom states that they might be a mixture of both populations. New analyses of AMMs and IR cometary observations strongly favour a cometary origin.

Seventy one Antarctic micrometeorites from the small size fraction (25–50 µm) have been, for the first time, carefully studied using SEM and microprobe analysis [3]. Their texture and mineralogy as well as their bulk chemical composition are similar to those of the larger size fraction (100–400 µm) [2]. Thus, the micrometeorite population is homogeneous over a large size range, showing a very simple mixture of CM-type (~95%) and CI-type (~5%) chondritic material. In contrast, a mixture of asteroidal and cometary debris should include a large diversity of particule types.

The variations of the micrometeorite flux with heliocentric distance measured by Ulysses was already compatible with a cometary origin of the dust. This view has been recently supported by the IR emission of the dust from comet Hale-Bopp. Far from perihelion, at 2.9 AU, crystalline olivine was discovered by ISO [4]. More recent observations at small heliocentric distances (<1.7 AU) from the ground detected crystalline pyroxenes [5]. These two minerals are the two major minerals in micrometeorites [2]. Furthermore, the pyroxene/olivine ratio measured in Comet Hale-Bopp dust (>3) is found to be similar to that measured in micrometeorites [2] where this ratio (~1) is ten times higher than in CM-chondrites (the meteorite group most similar to micrometeorites).

These new evidences make it likely that Antarctic micrometeorites originate from comets and therefore are, together with stratospheric interplanetary dust particles, the dominant and most primitive extraterrestrial material found on Earth.

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SEARCH FOR PRESOLAR SILICON CARBIDE IN MICROMETEORITIC MATERIAL IN A CRYOCONITE SAMPLE FROM GREENLAND ICE.

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We report results from a search for presolar SiC grains in an acid resistant residue of a Cryoconite sample. Cryoconite is a sediment that forms in the melt zone of the Greenland ice sheet at the bottom of shallow holes with sizes ranging from a few cm to that of the largest temporary freshwater lakes (about 500 m). It consists of siderobacteria cocoons, which enclose particles in the micrometer to millimeter size range. Some of these particles are of extraterrestrial origin [1]. 1 kg of Cryoconite contains about 1000 melted and unmelted cosmic spherules with sizes larger than 100 micrometers. It has been suggested that a significant fraction of micrometeorites is of cometary origin [2]. Comets are believed to be the most primitive material in the solar system and are thus expected to contain large amounts of presolar grains. The aim of our work was to answer the question whether or not the abundance of presolar SiC in the micrometeorites is distinctly larger than that in carbonaceous chondrites.

About 800 g of Cryoconite was chemically treated with Hydrogen Peroxide, yielding a mineral residue of 373 g. After a colloidal main silicate extraction, a series of HF/HCl cycles was applied to remove the rest of the silicates. The residues were then kept in HF at 165 degrees Celsius for eleven days to remove Kyanite, which was observed to be a major constituent of the residue [3]. After a density separation using Clerici's solution, a sample in the density range from 2.0 to 3.4 g/cm^3 was transferred to a gold foil and screened by ion imaging at low mass resolution with the University of Bern ion microprobe to locate SiC grains, as well as O-rich grains. Image processing recognized 202 SiC grains and 12500 O-rich grains on the sample mount. 56 of the SiC grains were subsequently analyzed for their C- and Si-isotopic composition using the conventional SIMS analysis technique. For all grains that were analyzed, the isotopic compositions of both Si and C are terrestrial within analytical uncertainties. The absence of presolar grains sets an upper limit of 0.3 ppb to the abundance of presolar SiC in the mineral fraction of our Cryoconite sample. This abundance estimation holds for SiC grains with diameters larger than about 0.5 micrometers, because ion imaging does not reliably detect SiC grains with smaller diameters.

From the mass distribution [4] and the observed abundance of extraterrestrial particles with sizes larger than 100 micrometers in Cryoconite, the abundance of extraterrestrial material in our mineral fraction is estimated to be 30 ppm. Assuming that all SiC survives the melting of the micrometeorites during atmospheric entry, we infer an upper limit on the abundance of presolar SiC in the extraterrestrial material in Cryoconite of 10 ppm. Even when we consider the uncertainties on the detection efficiency of SiC by ion imaging and on the abundance of micrometeorites in Cryoconite, our results suggest that the abundance of presolar SiC is not significantly higher in this material than the several ppm observed in the Murchison carbonaceous chondrite [5]. Further work is needed to verify this statement which implies that only a small fraction of micrometeorites originates from comets, or that comets do not contain a significantly larger fraction of presolar SiC than the carbonaceous chondrites.

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A PETROLOGICAL-CHEMICAL CLASSIFICATION SCHEME FOR COARSE-GRAINED MICROMETEORITES. M. J. Genge and M. M. Grady, Department of Mineralogy, The Natural History Museum, Cromwell Road, London SW7 5BD, Great Britain (m.genge@nhm.ac.uk).

Introduction: Micrometeorites (MMs) are that fraction of the extraterrestrial dust flux to be recovered from the Earth's surface and potentially provide samples of every low eccentricity small body in the solar system with an aphelion >1.0 AU. Three general varieties are recognised: (1) cosmic spherules, (2) fine-grained MMs, and (3) coarse-grained MMs (cgMMs). Cosmic spherules are those dust particles that have experienced high temperatures during entry heating and formed highly fluid droplets [1]. Fine-grained and coarse-grained particles are those that evidently had precursors with grain sizes significantly less than or approaching particle size respectively. Coarse-grained micrometeorites have not been studied in the same detail as other particle groups. We present data on the mineralogy and petrology of 40 cgMMs 50-400 μm in size recovered by melting and filtering of Antarctic blue ice [2] and suggest a petrological-chemical classification scheme for cgMMs.

Texture and Mineralogy: Two textural varieties of cgMMs were identified: (1) single crystal particles and (2) polycrystalline particles (PCPs). All cgMMs observed in the current collection are dominated by anhydrous silicate phases, mainly olivines and pyroxenes, although many also contain accessory kamacite, chromite and troilite grains, plagioclase feldspars and glassy mesostasis. A single particle also contains minor silica.

Single crystal particles (SCP) consist entirely of a single continuous crystals, but may contain minor Ni-poor, Fe metal droplets (presumably exsolved due to reduction), and glassy inclusions that probably represent trapped melt.

Polycrystalline particles exhibit considerably more textural variation and generally represent aggregates of anhydrous silicates with magmatic textures, although some particles with granular textures also occur. Three main textural varieties of PCPs were observed: (1) porphyritic particles dominated by phenocrysts and microphenocrysts in glassy mesostases, (2) granular particles which lack significant mesostasis, and (3) glassy particles that are dominated by glass with only minor quench crystals. These three textural groups can be further subdivided on the basis of their dominant mineral phases following the scheme proposed for chondrules by Gooding and Keil [3]. Thus porphyritic coarse-grained particles dominated by olivine and pyroxene are termed POP particles.

Polycrystalline particles can be further be divided on the basis of mineral compositions into three subtypes: (1) unequilibrated, (2) equilibrated, and (3) indeterminant. Unequilibrated particles are considered those with (a) chemically zoned phenocrysts, (b) olivines containing >0.1 wt% CaO and/or (c) disequilibrated pyroxene and olivine major element compositions. These can therefore be related to type 3 chondrites [e.g., 4]. Equilibrated particles are considered those that have both equilibrated Fs:Fa ratios and olivine Ca contents <0.1 wt% and can be related to type 4–7 chondrites [e.g., 5]. The absence of chemical zoning is not taken as indicative of equilibration. Those particles which lack any of the above features are described as indiscriminant.

Implications: The magmatic textures of cgMMs in combination with their mineralogies and mineral compositions broadly resemble those of chondrules. The observation that unmelted fine-grained MMs are closely related to CM2 chondrite matrix [e.g., 6] implies that the accompanying coarse-grained particles are fragments of CM2 chondrules. However, no hydrous alteration is observed in unequilibrated porphyritic particles to suggest these were components of type 2 chondrite parent bodies, implying a type 3 source. The equilibrated particles likewise suggest parent bodies different from CM2s with affinities to equilibrated ordinary chondrites. The preservation of glass in the few equilibrated porphyritic particles suggests derivation from a petrologic type 4 source.

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POPULATIONS OF LOW EARTH ORBIT PARTICLES: SIGNIFICANT OTHER OR SIMPLY SPACE JUNK?

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Introduction: Whilst much research has been carried out on terrestrial collections of cosmic dust [e.g. 1,2], very little has been undertaken on particles collected from low Earth orbit (LEO). In principle such material should yield the best representation of micro-particle populations as they are not subject to the selection and modification processes which occur during atmospheric transit by both IDPs and micrometeorites (MMs) [3]. Previous collections of LEO material have focused around dedicated in-situ collector experiments [4,5], which are expensive and often only single-flight opportunities. Whilst the benefits and knowledge gained from these investigations are not in doubt, it is perhaps questionable whether the maximum yield of information was obtained. Such investigations are inherently difficult as particles travelling at hypervelocity speeds (5-20km/s) maybe subject to melting and devolatilisation during impact. However, the advent of NASA's 'Stardust' mission has led to development of technologies to overcome such problems [6]. Other attempts at LEO sampling have employed passive collectors, e.g. space hardware which has been subject to hypervelocity impact (HVI) damage [7]. The value of such studies to the cosmic dust community is also questionable, as only rarely are near pristine particles observed [8]; usually only complex mixed melt-derived impactor and host residues are identified [9]. A further complication to such collections is the presence of a second population of space debris, artificial in nature and generated by human utilisation of LEO. It is this population which has often been the focus of LEO studies [6]. Notwithstanding such difficulties, herein we report observations made on (1) solar cells removed from the Hubble Space Telescope after 3.65 years in LEO environment. (2) Hyper-velocity impacts (HVIs) simulated in the laboratory, using known meteoritical mineralogies.

Experimental: The simulated impacts were undertaken using powders (125–250µm grain diameter) to allow detailed classification of residues and direct comparisons with IDPs and MMs. Powders were prepared from carefully selected individual minerals (known to be homogenous in composition and similar to those identified in IDPs and MMs, e.g., olivine, calcite, pyrrhotite, etc.), plus Orgueil matrix (to provide a heterogeneous range of compositions). These sabot-mounted samples were individually accelerated in a light-gas gun to impact on solar cell targets at velocities around 5km/s. The purpose of these experiments was to observe any remaining volatile chemistry after HVI (e.g., by calcite) and to categorise how different minerals produce melt residue (i.e., degree of mixing with the host). Both the laboratory impacts and those generated in LEO were examined using a scanning electron microscope [10].

Results: The simulated HVI experiments have thus far suggested that the textural features of residues are partly dependent on the mineralogy of the impactor. We note that when using calcium carbonate as an impactor, volatile elements such as Ca, can remain after HVI onto the substrate. The Ca-bearing particles appear as fragments (<8 µm), rather than as typical melt residues previously observed for other minerals. They are not simply pristine mineral grains, artefacts of the experiment, as there is evidence of surface melting and coating by melted CMX glass.

The natural micrometeoroid residues can be classified by elemental signatures [4] and textural morphology into the following: mafic in origin (olivine/pyroxene); metallic sulfides (Fe- & Fe-Ni); metal (Fe-Ni with meteoritical ratios); probable phyllosilicates; altered refractory mineralogies. The investigations of the space flown solar cells also indicated that the majority (75%) of impacts in the 100–1000µm diameter crater range were caused by natural micrometeoroids and not artificial space debris, as previously suggested [4]. This finding raises the possibility that LEO may harbour a previously underestimated population of cosmic dust. Re-examination of the known-orbital-orientation surfaces of LDEF using [10] might resolve whether such particles are significant in number.

Conclusion: This study has proven that solar cell surfaces can provide substantial information as to impactor composition and that such investigations have a value to the understanding of cosmic dust in LEO.

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PRODUCTION OF CARBON COMPOUNDS IN THE SOLAR NEBULA BY CO HYDROGENATION OVER METAL PARTICLES: IMPLICATIONS FOR IDPs. J. Llorca[1,2] and I. Casanova[1,3], [1]Institut d'Estudis Espacials de Catalunya, Edifici Nexus, Gran Capità 2-4, 08034 Barcelona, Spain. [2]Dept. Química Inorgànica, Universitat de Barcelona, Diagonal 647, 08028 Barcelona, Spain (jllorca@kripto.qui.ub.es), [3]ETSECCPB, Mòdul C1, Universitat Politècnica de Catalunya, 08034 Barcelona, Spain.

Introduction: Carbonaceous phases in primitive chondrites and interplanetary dust particles may provide a singular record of organic chemical evolution as well as information on chemical composition and physical conditions in the early solar system. Although there exist a considerable amount of work directed towards the identification of the structure and composition of these carbonaceous phases, their origin is not well understood. There are various processes which may partially explain their occurrence. One of such mechanisms assumes that the simultaneous formation of organic molecules and carbonaceous phases took place in the solar nebula via catalytic reactions between the gas molecules and solid phases which served as active catalysts. This model is commonly referred to as the Fischer-Tropsch-type mechanism and has often been assumed to possibly account for the formation of carbonaceous rims on metal and metal-derived grains in carbon-rich aggregates in chondrites [1] and interplanetary dust particles [2].

In order to test to what extent Fischer-Tropsch-type processes operating in the solar nebula may explain these C assemblages, we have carried out detailed laboratory studies in order to simulate the interaction between silica-supported nanometer-sized model iron and kamacite particles (ca. $Fe_{95}Ni_5$), similar to those present in chondritic porous IDPs, and different gas mixtures under nebular-type conditions, 5×10^{-4} atm and 423–523 K. After 500–1000 hr of reaction, the resulting solids have been characterized by transmission electron microscopy and X-ray photoelectron and infrared spectroscopies.

H_2+CO experiments: Exposure of metal kamacite particles to a H_2+CO gas mixture (H_2:CO = 250:1) at 5×10^{-4} atm and 473 K results in the formation of volatile hydrocarbons, ε-carbide and non-graphitic poorly crystalline carbonaceous layers, which are indeed similar to those reported in C-rich aggregates in chondritic porous IDPs [3]. As expected, C deposition in the range 423–523 K is favored as temperature increases. The syntheses of hydrocarbons, carbides and carbonaceous phases appear to be related processes, which are all enhanced over kamacite particles with respect to iron particles, in accordance to the relative stabilities of their respective carbides [4].

H_2+CO+H_2S experiments: The possibility of catalyst poisoning by sulfur in the CO hydrogenation reaction due to the presence of H_2S in the nebular gas has also been investigated. Exposure of model kamacite particles to a H_2+CO+H_2S gas mixture (H_2:CO:H_2S = 250:1:0.1) at 5×10^{-4} atm and 473 K results in the formation of hydrocarbons and sulfur-containing organic molecules as well as sulfide, carbide and non-graphitic carbon rims. There is no evidence of sulfur poisoning effects under nebular conditions. In contrast, the addition of H_2S to the reactant gas promotes the formation of organics and carbonaceous phases. The promoter effect of H_2S may be related to the sulfide-carbide assemblage present on the surface of the solids, which can be more reactive than carbide alone.

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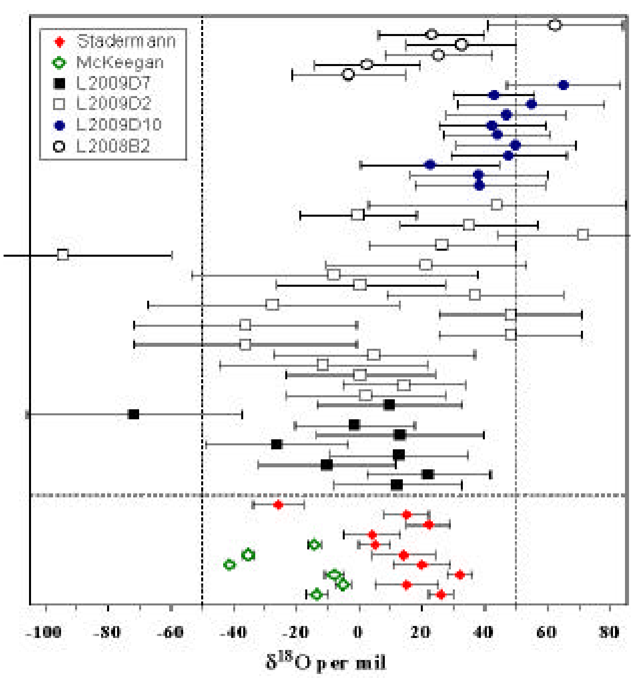
OXYGEN ISOTOPIC IMAGING OF INTERPLANETARY DUST. S. Messenger, National Institute of Standards and Technology, B222/A113, Gaithersburg MD 20899, USA (scott.messenger@nist.gov)

Introduction: Several characteristics common to many interplanetary dust particles (IDPs) suggest that some of these particles may be chemically, mineralogically, and texturally primitive in comparison to meteorites [1]. Many IDPs exhibit substantial enrichments in volatile elements relative to CI chondrites [2], and are often characterized by a fine-grained, unequilibrated mineralogy [3]. Hydrogen and nitrogen isotopic anomalies are also common among chondritic IDPs, likely due to the presence of relict presolar molecular cloud material [4-6]. These anomalies are most prominent among cluster IDPs (particles found fragmented on IDP collectors) where D/H ratios in some particles exceed values observed in meteorites, and are highly variable on a µm scale [6].

These observations raise the possibility that presolar materials are more abundant and better preserved in some IDPs than in meteorites, potentially including presolar phases not yet observed in meteorites (*e.g.* silicates). Presolar grains are recognized by their exotic isotopic composition [7]. However, none of the circumstellar phases observed in meteorites have yet been found in any IDP. This is not surprising if the circumstellar grain abundance in IDPs is not significantly larger than that observed in meteorites (~10 ppm) [8]. Alternatively, it is possible that such grains are common in IDPs, but have not been detected because most isotopic measurements have been performed on entire 10-15 µm IDPs, while typical interstellar grains are 0.1-1 µm in size. Presolar grains may thus only be detectable by performing isotopic measurements of IDPs on a much smaller spatial scale.



In order to develop a more effective search strategy for interstellar grains in IDPs, I have initiated a C and O ($^{16}O/^{18}O$) isotopic survey of cluster IDPs by ion microprobe microbeam imaging. Here, a finely focused primary ion beam is rastered over the sample, while the secondary ions are synchronously detected with an electron multiplier. The spatial resolution of the resultant mass-filtered ion map is chiefly limited by the primary beam diameter, which is estimated here to be ~0.5 µm. This technique has been previously employed to study H and N isotopic heterogeneity in several IDPs [9,10]. Here I report the initial results for four cluster IDPs previously observed to have substantial deuterium excesses.

Each of the IDPs studied (L2009D10 cluster 10, L2009D7 cluster8, L2009D2 cluster 3, L2008B2 cluster 4) was exposed to a ~5 pa Cs' primary ion beam, with 50 cycles of alternating (10 second) $^{16}O^-$ and (60 second) $^{18}O^-$ images acquired at low mass resolving power. Individual pixels in each image were corrected for instantaneous deadtime, with instrumental mass fractionation determined by imaging Burma spinel standard grains under similar conditions. The Figure compares the $^{16}O/^{18}O$ ratios of 46 (~1-3 µm) subregions within the IDPs with previous IDP measurements [11,12]. The vertical dashed lines delineate the approximate range in $^{16}O/^{18}O$ ratios of terrestrial minerals and refractory meteoritic inclusions. These initial results show no evidence for ~1 µm isotopically exotic interstellar grains in these IDPs. Limiting these maps to $^{16}O/^{18}O$ ratios excludes the possibility of detecting grains with normal ^{18}O and anomalous ^{17}O. However, since these images can be acquired at low mass resolving power, the overall detection sensitivity should be significantly higher.

Future work will include C isotopic imaging, as well as targeted imaging of GEMS-rich IDPs.

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FIELD-EMISSION SCANNING ELECTRON MICROSCOPY AND TRANSMISSION ELECTRON MICROSCOPY STUDY OF INTERPLANETARY DUST PARTICLES FOR THE ROSETTA MISSION.
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Investigating pristine cometary dust should shed light on the study of the solar system formation since comets are believed to be the most primitive bodies in the solar system [1]. The cometary mission *Rosetta* proposed by ESA will be launched in the year 2003 and after its eight-year journey the satellite will rendezvous with comet Wirtanen and study its nucleus and environment [2]. MIDAS (Micro Imaging Dust Analysis System) is one of the on-board instruments imaging cometary dust for the first time. The MIDAS experiment is based on an atomic force microscope (AFM) combined with a dust collector [3] expected to image individual particles with a resolution of 4 nm.

In order to interpret the images obtained by the AFM microscope a database of morphologies and correlated internal textures of various materials is needed as a reference. Experiments are under way on artificial cometary-like materials like Fe-Mg-silica smokes as well as on interplanetary dust particles [4].

Our study concentrates on comparison of surface features of IDPs seen in SEM and/or AFM with the interior properties of IDPs, like grain sizes and porosities, determined by TEM. Due to technical problems of sample handling and imaging we were so far not successful in obtaining good AFM images of IDPs. Instead field-emission scanning electron microscopy (FE-SEM) was used to obtain high-resolution images (approx. 15nm at 1.0kV) of the surface of IDPs. Before imaging, the IDPs were carefully rinsed with hexane to remove the adhering Si-oil. After that, the particles were mounted on a thin layer of easily dissolvable glue. 14 particles were studied with the FE-SEM at 1 kV, with a SEM at 15 kV and subsequently with TEM.

The FE-SEM micrograph in Fig. 1 displays the surface morphology of an interplanetary dust particle. Small rectangular crystallites appear to be attached to the surface and larger crystals and some fine-grained material seem to make up the interior of particle *L2008E4*. The morphology as well as the chemical composition of this IDP is remarkable, because micrometer-sized euhedral crystals are not common in the interior of IDPs, and the particle contains high amounts of sodium and phosphorus (on the order of 8 and 14 wt% respectively). Studies of ultramicrotome sections showed the presence of nice hexagonal and rectangular euhedral crystals varying from several hundred nanometers to several micrometers in size throughout the whole particle. In the case of a compact particle (*L2009K18*), which appears partly melted in the SEM, the interior consists of small crystals set into an amorphous matrix.

Morphological features and interior textures correlate well in these and other cases. It looks very promising that a database containing a wide variety of IDP surface features and correlated interior textures can serve as a tool to interpret AFM images acquired during the ROSETTA mission..

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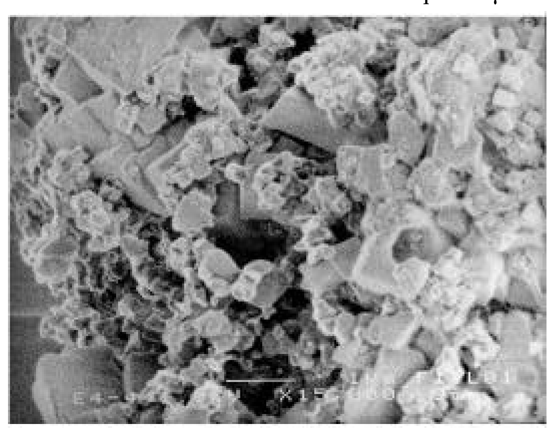
Figure 1. High resolution FE-SEM image of chondritic IDP *L2008E4*. The scale bar equals 1µm.



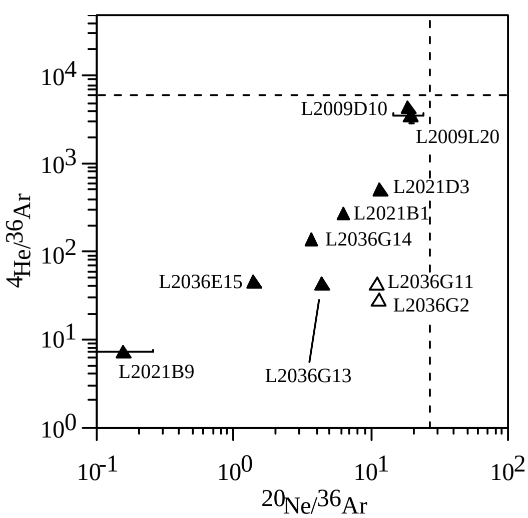
HELIUM, NEON, AND ARGON MEASURED IN LARGE STRATOSPHERIC DUST PARTICLES. K. Kehm[1], G. J. Flynn[2], S. R. Sutton[3], and C. M. Hohenberg[1], [1]McDonnell Center for Space Sciences, Washington University, St. Louis MO 63130, USA (charlie@radon.wustl.edu), [2]Department of Physics, State University of NewYork-Plattsburgh, Plattsburgh NY 12901, USA, [3]Department of Geophysical Sciences, University of Chicago, Chicago IL 60637, USA.

Introduction: Interplanetary dust particles (IDPs) collected in the earth's stratosphere are rich in noble gases implanted from exposure to solar corpuscular radiation [*e.g.* 1,2]. Previously we reported the results of combined trace-element and noble-gas measurements on individual IDPs from the L2036 high-altitude collector. These measurements confirmed the presence of multiple solar-derived components including solar wind (SW) and solar energetic particles (SEP), along with the possible presence of spallogenic Ne in one gas-poor particle [2]. Zinc depletions, previously shown to be linked to instances of severe atmospheric entry heating [3], were observed in several of these IDPs. Relatively low surface-normalized He content was observed in this Zn-poor subset, consistent with the notion that both He and Zn were lost during hypervelocity atmospheric deceleration.

Experiment: In our ongoing effort to understand the space exposure history of IDPs in the context of their chemical compositions and collection times, we have performed trace element and noble gas measurements on a set of large (~20 μm) stratospheric dust particles. Ten of these particles were identified as cosmic on the basis of their major element compositions while three were designated as terrestrial contamination natural (TCN). Trace elements were measured using synchrotron X-ray fluorescence at Brookhaven National Lab. Subsequently, noble gases were measured in each grain using the focused-laser extraction apparatus at the Washington University noble gas lab.

Results and Discussion: The figure shows the $^{4}He/^{36}Ar$ and $^{20}Ne/^{36}Ar$ ratios for each IDP in this study. The dashed lines give typical element ratios for solar-irradiated lunar ilmenites, the most gas-retentive lunar minerals [4]. Consistent with our previous results [2], none of the TCN particles contained detectable noble gases, suggesting that cosmic dust can be identified on the basis of gas *content* alone. Solar particle implantation is evident in all IDPs measured in this study, in some cases possessing $^{4}He/^{36}Ar$ and $^{20}Ne/^{36}Ar$ ratios, and gas concentrations approaching the lunar-ilmenite values.

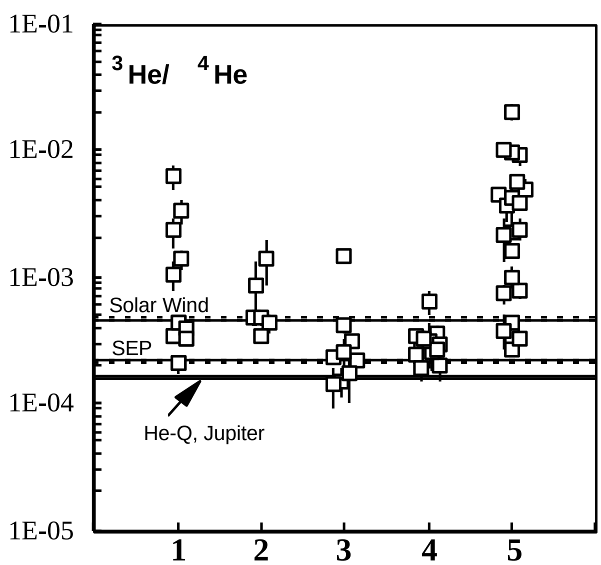
Zinc-depleted particles (Zn/Fe < 0.3xCI) L2036G11 and L2036G2 are plotted as open triangles in the figure. Note that these two grains, along with L2036G13 which also demonstrated a marginal Zn-depletion (Zn/Fe ~0.35×CI), have similar $^{20}Ne/^{36}Ar$ ratios but *lower* $^{4}He/^{36}Ar$ ratios than their non-Zn depleted counterparts. Moreover, other than L2021B9, these three grains are the most He-poor in the set, with surface-normalized He concentrations similar to those previously observed in Zn-depleted IDPs [2]. These observations are qualitatively consistent with L2036G11, L2036G2 and L2036G13 having experienced He loss during atmospheric entry heating. If so, there is a hint that He is lost more readily than Ne in these particles as might be expected on the basis of simple mass-dependent fractionation of the noble gas pattern during flash heating. Further modeling and additional data will help to clarify this issue.



References: [1] Nier A. O. and Schlutter D. J. (1993) *Meteoritics, 28,* 675–681. [2] Kehm K. et al. (1998) *LPSC XXIX.* [3] Flynn G. J. and Sutton S. R. (1992) *Proceedings of LPS, 22,* 171–184. [4] Nichols R.H. et al. (1994) *GCA, 58,* 1031–1042.

EXCESS HELIUM-3 IN INTERPLANETARY DUST PARTICLES. R. O. Pepin and D. J. Schlutter, School of Physics and Astronomy, University of Minnesota, 116 Church Street S.E., Minneapolis MN 55455, USA.

Sixty IDPs, both individual particles and fragments of larger grains ("cluster" IDPs), have been analyzed at Minnesota for ^{4}He contents and ^{3}He/^{4}He ratios. Suites 1-2 in the Figure are new results on individual IDPs in the ~7–60pg (~20–7µm) mass/size range; the others are earlier measurements on mostly individual particles in suites 3-4 [1,2], and on cluster fragments from the L2005-L2006-L2011 collector flags in suite 5 [3]. There is now considerable interest in the Flag-L particles as a result of recent arguments that some of them may derive from comet Schwassmann-Wachmann [4]. About half of the ^{3}He/^{4}He determinations fall in an "expected" range, from meteoritic He-Q [5] up through the solar-energetic-particle (SEP) and solar-wind (SW) ratios [6] reflecting exposure to solar ion irradiation during the residence times of these particles in space. The others display enhanced ratios, in suite 5 by factors of up to ~20-40, with respect to SW-^{3}He/^{4}He. The central question is the source(s) of this excess ^{3}He.



The most obvious possibility is that high-^{3}He/^{4}He grains record exposure to galactic (GCR) and solar (SCR) cosmic rays. Minimum GCR-SCR exposure ages, ignoring possible diffusive or recoil losses of spallogenic ^{3}He, may be estimated from the amounts of excess ^{3}He required to elevate observed ^{3}He/^{4}He ratios above the SW value, and Reedy's [7] GCR/SCR production rates for small objects in space. We calculate impossibly long CR exposure ages for the suite 1-2 individual IPDs: ~20 Gy for the two highest in ^{3}He/^{4}He, and ³ 8 Gy for three others. Most suite 5 cluster IDPs are He-poor compared to individual particles [3,4] and their inferred CR-ages are correspondingly lower, ranging from ~0.05 to 1.2 Gy; however their average of ≈230 My still greatly exceeds expected IDP lifetimes in the inner solar system. Long residence times as small particles in the outer system or pre-irradiation of their parent objects could be possibilities. But our suspicion is that some other, currently unidentified source of ^{3}He is responsible for the excesses in all of the IDPs.

There are two constraints on attributing anomalous ^{3}He contents to irradiation by, for example, ^{3}He-rich solar flares or interstellar pick-up ions: (a) half of the IDPs are unaffected, and (b) one would expect such fluxes to be recorded in lunar surface materials. But the concentration of excess ^{3}He in the two most anomalous suite 1 particles is >1000 times above that attributed to solar-flare implantation into the surface of lunar rock 68815 over the past 2 My [8]. It appears necessary to look elsewhere, for cometary particles perhaps back to a pre-solar molecular cloud environment, for a plausible ^{3}He source.

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HYDROGEN, NITROGEN, AND NEON ELEMENTAL AND ISOTOPIC CONSTRAINTS ON COMETARY AND METEORITIC FLUXES.

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The flux of matter falling on terrestrial planets was heavier in the past than at present as shown by the moon cratering record [1]. The late bombardment of extraterrestrial matter rich in volatiles (i.e., comets and carbonaceous chondrites, VRM—volatile rich matter) could have contributed to the Earth's atmosphere (as a whole). Such extraterrestrial contribution would have left its isotopic fingerprint in the Earth isotopic record (e.g., cometary water is enriched in deuterium relative to the oceans by a factor 2 [2 and references therein]). Here, we develop an isotopic and chemical approach that allows to estimate the flux of VRM fallen on Earth throughout its history (Md) as well as the relative fraction of comets in the VRM (f=comets/VRM).

The Earth presents an isotopic disequilibrium between the atmosphere and the mantle; the surface reservoirs are depleted in light isotopes relative to the mantle (i.e., the $^{22}Ne/^{20}Ne$, $^{15}N/^{14}N$ are higher in the atmosphere than in the mantle [3–5]). Such disequilibrium can not simply be accounted for by isotopic fractionation during subduction-zone metamorphism [5,6]. In addition, rare gases (e.g., Ne) are unlikely to be quantitatively recycled via subduction [7]. So far, two explanations were envisioned to account for this disequilibrium: (a) The early atmosphere (primary or secondary) endured a period of fractional loss of its volatiles. (b) The Earth endured a period of heavy bombardment (i.e. addition of a late veneer).

Here, we assume that the Earth's isotopic disequilibrium (at least for Ne and N) arises from the late bombardment of VRM, the primitive Earth being isotopicaly homogeneous. In this frame, the lowest D/H [8], $^{15}N/^{14}N$ [9], and $^{22}Ne/^{20}Ne$ [3,4] ratios reported so far in the Earth's mantle could represent the primitive Earth values.

The extraterrestrial flux is, in a large measure, composed of carbonaceous matter, as shown by the moon trace-element pattern [10] and by the present day asteroid-belt population [11]. Among carbonaceous chondrites, CI and CM match the best the spectra of C-asteroids [12]. At first sight, the flux of VRM fallen on the Earth throughout its history can be seen as a mixture of comets and carbonaceous chondrites (i.e., CI/CM).

Erosion of the Earth's atmosphere by impacting bodies is highly model-dependant. We will follow Walker [13] in considering that the Earth retained all incident volatiles. If we assume the Earth to be conservative, we can draw an isotopic (i_E) and an elemental (ii_E) mass balance for any element E (subscripts p, i, o and c refer to the present-day Earth, the primitive Earth, comets, and carbonaceous chondrites respectively. α and β are two isotopes of E. $M_\oplus$ is the mass of the Earth. $\delta^{\beta\alpha}E_{SAMPLE}=[(^{\beta}E/^{\alpha}E)_{SAMPLE}/\ (^{\beta}E/^{\alpha}E)_{STD}-1] \times 1000$, $\Delta^{\beta\alpha}E_{mn}=\delta^{\beta\alpha}E_m-\delta^{\beta\alpha}E_n$. $C^{\alpha}E_m$ is the concentration of the α isotope of E in m). (S_E) system (unknown parameters are in bold):

$$(i_E)\quad \mathbf{Md} = \frac{M_\oplus . C^{\alpha}{}_{E_p} . \Delta^{\beta\alpha}{}_{E_{ip}}}{C^{\alpha}{}_{E_o} . \Delta^{\beta\alpha}{}_{E_{io}} . \mathbf{f} + C^{\alpha}{}_{E_c} . \Delta^{\beta\alpha}{}_{E_{ic}} . (1-\mathbf{f})}$$

(ii_E)

$$M_\oplus . \mathbf{C}^{\alpha}{}_{\mathbf{E_i}} = M_\oplus . C^{\alpha}{}_{E_p} - \mathbf{Md} . (\mathbf{f} . C^{\alpha}{}_{E_o} + (1-\mathbf{f}) . C^{\alpha}{}_{E_c}) \quad (\geq 0)$$

Recent measurements of cometary D/H [2] and $^{15}N/^{14}N$ [14] ratios make it possible to solve S_E system (two unknowns - f, Md - with two equations -i_H, i_N).

The mass (Md) of impacting bodies (VRM) fallen on Earth since 4.5 Gyr is set within ~1×10^{21} kg–1×10^{22} kg, which is in remarkably good agreement with time-integrated fluxes derived on physical grounds by Chyba [1]. In addition, the relative fraction of comets (f) can not exceed ~20%. If we assume the $^{20}Ne/^{22}Ne$ ratio to be solar in comets, then a fractionation process is required [15]. Our approach offers the sole opportunity to constrain the contributions of comets and carbonaceous chondrites to the Earth's volatile inventory.

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ELEMENT AND ISOTOPIC ANOMALIES IN PEAT FROM THE TUNGUSKA EXPLOSION (1908) AREA ARE PROBABLY TRACES OF COMETARY MATTER.
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Tunguska Cosmic Body (TCB) seems to be nuclear of small comet [1]. Any fragments of TCB have not been discovered. To search for the TCB remnants, peat Sphagnum fuscum sampled at the explosion area has been investigated for many years [2]. In the "catastrophic" peat layers, including the 1908 growth-up, silicate microspherules have firstly been found. They occurred to be enriched in Na and Zn [3]. However, main cometary elements are H, C, N, and O. In order to determine the presence of cometary matter, we offered to do bed-by-bed isotopic analysis of these elements in the peat layers. In the "nearcatastrophic" layers of four peat columns, the anomalies in the isotopic composition of C and H have been revealed [4]. The shifts for carbon ($\delta^{13}C$ reaches +4.3‰) and hydrogen (δD reaches –22‰) may not be explained by fall-out of terrestrial mineral and organic dust or fire soot, by humification of peat, emission from the Earth of oil-gas streams or climate changes. Moreover, isotopic effects are clearly connected with the area and the time of the TCB explosion and are absent in the upper and the lowest peat layers, under 1908 boundary permafrost, and also in the control peat columns from other places. There is also correlation of isotopic effects and content of Ir [4,5] in peat.

Isotopic effects may not be explained by contamination of peat by matter similar to ordinary chondrites, they may be hardly explained by conservation in peat of dispersed CI matter, but may be more probably explained by cometary matter presence. The N content and its isotopic composition in peat [4] are consistent with the assumption of acid rain fall-out, as known for the K/T boundary sediments.

In this work we analysed the acid washings-out of peat using ICP-MS. At the same depth, between the "catastrophic" layer and 1908 permafrost boundary, we revealed the significant increase of some element concentrations: Mg, Al, Si, K, Ca, Sc, Ti, Fe, Co, Ni, Sr, Pd. The most sharp increase was shown for alkaline metals: Li, Na (500 times), Rb, Cs and some other volatile elements: Cu, Zn, Ga, Br, Ag, Sn, Sb, Pb, Bi. Concentrations of Si and Na were the largest (~10%), the latter is in agreement with the high Na concentration in spectrum of many comets (for example, Ikeya-Seki [6]) and meteors. Composition of anomalous elements is mainly consistent with composition of them in peat ash [7].

The effects obtained in peat couldn't be caused by fall-out of terrigenic dust. As compared to trapps, in substance preserved in peat the concentration of other main elements (Mg, Al, Ca, Ti, and Fe), relative to Si, is abruptly decreased, whereas the content ratios of Mg/Al and Ni/Fe are significantly increased. Moreover, the ratios of hard volatile elements Al/Ca/Ti are different from that of trapps, and there is manifold enrichment by some volatile elements (Na, Br, Rb, Ag, Sn, and Pb).

Supposed TCB matter, preserved in peat, is depleted of Fe and other siderophilic elements as compared to ordinary meteorites. At the same time, even relative to chondrites CI, it is sharply enriched with many volatile elements that is typical for IDPs which are the products of comet disintegration [8].

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